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NAVY EXPERIMENTAL DIVING UNIT

DEPARTMENT OF THE NAVY
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Panama City, Florida 32407

NAVY EXPERIMENTAL DIVING UNIT

REPORT NO. 3-80

UNMANNED EVALUATION OF U.S. NAVY MK 11 MOD 0 SEMI-CLOSED CIRCUIT MIXED GAS UBA

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June 1980

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NEDU performed unmanned tests on the MK 11 UBA incorporating Field Change Number 979A (modified canister configuration containing a heated central core and Koegel check valves in the M-11 mask). Breathing resistance and canister duration were evaluated at depths ranging from 250 to 750 fsw. Results showed breathing resistance to be significantly improved over previous designs and capable of supporting heavy work at depths to 650 fsw. Canister durations were improved to 450 fsw; however, most of this improvement was lost at 650 fsw in water below 40°F.

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GLOSSARY

BPM	breaths per minute
Canister Breakthrough	point at which CO_2 concentration in the breathing gas reached 0.5 percent surface equivalent
°C	temperature in degrees Centigrade
cm H_2O	centimeters of water pressure (differential)
CO_2	carbon dioxide gas
EDF	Experimental Diving Facility
EOD	Explosive Ordnance Disposal
°F	temperature in degrees Fahrenheit
gpm	gallons per minute
H.P. Sodasorb	high-performance Sodasorb
H_2O	water
kg m/l	work of breathing per liter of ventilation
LPM	liters per minute (flow rate)
LTV	tidal volume (liters)
NEDU	Navy Experimental Diving Unit, Panama City, Florida
OSF	Ocean Simulation Facility
O_2	oxygen
P_{O2}	partial pressure of oxygen
ΔP	pressure differential (cm H_2O)
psig	pounds per square inch gauge
RMV	respiratory minute volume in liters per minute
SEV	surface equivalent value
sd	standard deviation
T in	temperature of inspired gas
T exp	temperature of expired gas
UBA	underwater breathing apparatus

ABSTRACT

NEDU performed unmanned tests on the MK 11 UBA incorporating Field Change Number 979A (modified canister configuration containing a heated central core and Koegel check valves in the M-11 mask). Breathing resistance and canister duration were evaluated at depths ranging from 250 to 725 fsw. Results showed breathing resistance to be significantly improved over previous designs and capable of supporting heavy work at depths to 650 fsw. Canister durations were improved to 450 fsw; however, most of this improvement was lost at 650 fsw in water below 40°F.

INTRODUCTION

From June through September 1979 NEDU performed unmanned tests on the life support characteristics of the MK 11 MOD 0 Semi-Closed Circuit Mixed Gas UBA. Breathing resistance and CO_2 absorbent canister duration tests were conducted at depths ranging from 250 to 725 fsw. Water temperatures ranged from 29 to 40°F. All tests were conducted using the M-11 mask with Koegel check valves and a modified absorbent canister incorporating a heated central core (Field Change Number 979A).

EQUIPMENT DESCRIPTION

The MK 11 MOD 0 is a semi-closed circuit, mixed gas, underwater breathing apparatus and is designed for use in saturation diving operations at depths to 650 fsw. It contains a carbon dioxide absorbent canister which incorporates hot water heating by an external canister jacket, and internal heating via stainless steel tubing. Oxygen makeup is accomplished by various sized orifices with pressure controlled by an absolute pressure regulator. Emergency gas can be supplied in either the semi-closed or open circuit modes. The M-11 full face mask is used in conjunction with the MK 11 MOD 0 UBA and incorporates an oral-nasal mask, communications, open circuit emergency second state regulator, and inhalation/exhalation hoses which attach to the backpack for semi-closed circuit use.

FIGURE 1. MK 11 MOD 0 SEMI-CLOSED CIRCUIT MIXED GAS UBA

DESCRIPTION OF MK 11 MOD 0 TEST CONFIGURATION

The MK 11 MOD 0 UBA was set up in the EDF chamber complex as shown in Figure 2. Appendix B lists all equipment used during unmanned testing.

BREATHING RESISTANCE TESTS

The MK 11 MOD 0 UBA and M-11 mask were positioned in the wet test box in the EDF chamber. A 1.00 psid pressure transducer tapped into the oral-nasal mask to measure exhalation and inhalation pressures. The output of this transducer fed into an x-y plotter along with the output of a linear position transducer mounted on the breathing machine. The combination of these two inputs created the pressure-volume loops (P-V loop) on the x-y plotter from which breathing resistance and breathing work are computed. Ambient water temperature was 70°F and the exhaled gas was not heated or humidified. Parameters controlled, measured, computed, and plotted are listed under Test Procedures.

CANISTER DURATION TESTS

For canister duration tests the MK 11 MOD 0 and M-11 mask were positioned in the wet test box the same as for breathing resistance tests. Sample lines were connected to the inhalation and exhalation hoses which attached to the MK 11 backpack. These lines carried samples of the inspired and expired gas to the Beckman Infrared Analyzers which determined SEV CO_2 concentrations out of and into the canister. A closed-loop reservoir and pump assembly supplied hot water at the required temperature to the MK 11 absorbent canister at 2.5 gpm. Chilling coils in the wet test box from the EDF life support loops appropriately controlled the ambient water temperature. Diver exhaled gas was heated, humidified and laden with CO_2 in a manner consistent with an actual working diver. Parameters measured, controlled and plotted are outlined in the following section.

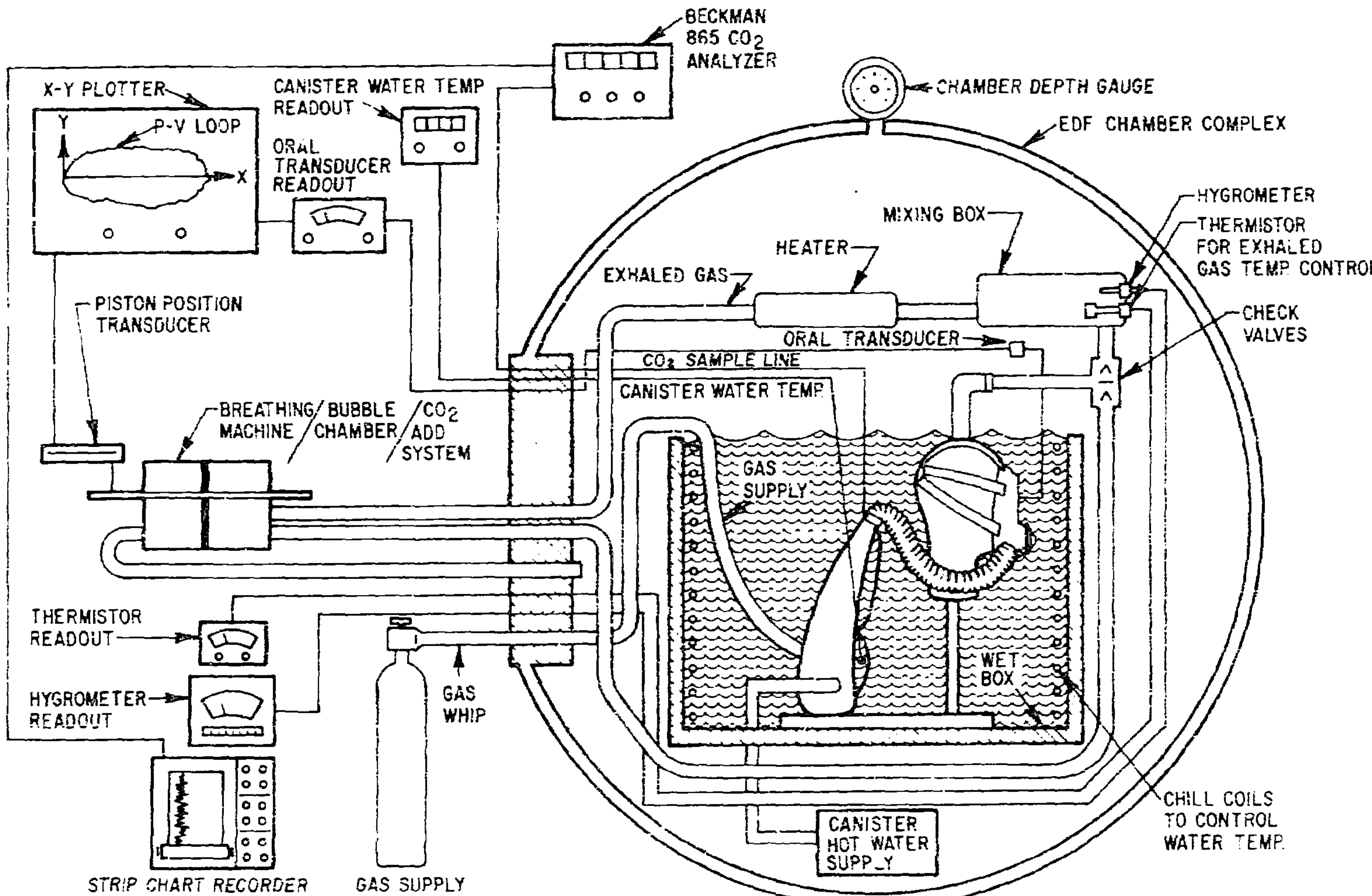


FIGURE 2. TEST SETUP

TEST PROCEDURE

TEST PLAN

The complete test plan is provided in Appendix A. All applicable NEDU test standards for unmanned testing were followed. Test equipment is listed in Appendix B and illustrated in Figure 2. A breathing machine simulated inhalation and exhalation at various depths and diver work rates.

CONTROLLED PARAMETERS

A. Breathing Resistance Tests

The following parameters were controlled for breathing resistance tests.

1. Breathing medium
   HeO_2 Mixes:

Depth (fsw)	250	450	650	725
($\%He/\%O_2$)	82/18	90/10	93/7	93/7

2. Breathing rate/tidal volume

Breathing rate/tidal volume	RMV	Simulated Diver Work Rate
a. 15 BPM/1.5 liters	22.5 RMV	Light
b. 20 BPM/2.0 liters	40.0 RMV	Moderate
c. 25 BPM/2.5 liters	62.5 RMV	Moderately Heavy
d. 30 BPM/2.5 liters	75.0 RMV	Heavy
e. 30 BPM/3.0 liters	90.0 RMV	Extreme

3. Exhalation/inhalation time ratio: 1.00/1.00

4. Breathing waveform: sinusoid

5. Incremental descent stops for breathing resistance tests: 250, 450, 650 and 725 fsw

6. Water temperature: 70°F

B. Canister Duration Tests

The following parameters were controlled for canister duration tests.

1. ·-eathing medium
   HeO_2 Mixes:

Depth (fsw)	250	450	650	725
($\%He/\%O_2$)	82/18	90/10	93/7	93/7

2. CO_2 breakthrough tests were conducted using H.P. Sodasorb at water temperatures of 40, 35 and 30°F (±2°).

3. CO_2 add rate:

   a. 0.9 LPM at 23.0 RMV (2.0 LTV x 11.5 BPM) during 4-minute rest cycle

   b. 2.0 LPM at 50.0 RMV (2.0 LTV x 25 BPM) during 6-minute work cycle

   NOTE: The CO_2 add rate is cycled between 0.9 and 2.0 LPM at 4- and 6-minute intervals, respectively, for the duration of the canister tests to simulate a man working at an oxygen consumption level of 1.56 LPM.

4. Relative humidity of exhaled gas: 90 percent relative humidity (±2 percent).

5. Control of exhaled gas temperature followed the formula that expired gas temperature equals 24 + 0.32 times inspired gas temperature (T exp = 24 + 0.32 T in °C). NOTE: "T in" was assumed to be 10°C above ambient water temperature.

Water Temperature (°F)	30	35	40
Exhaled Gas Temperature (°F)	80.3	81.3	83.5

6. Depth stops for canister duration tests: 250, 450, 650, and 725 fsw

7. Hot water temperature to CO_2 canister: 110°F and 95°F

8. Hot water flow rate to CO_2 canister: 2.5 gpm

9. The following matrix shows the depth and water temperature combinations which were studied to determine the canister duration scenario. A minimum of 4 tests were run at each set of test conditions.

Ambient Water Temperature (°F)		40	35	30
Canister Inlet Water Temperature (°F)		110/95	110/95	110/95
Depth (fsw)	250	--	X/-	--
	450	--	X/-	--
	650	X/-	X/X	X/X
	725	--	X/-	--

MEASURED PARAMETERS

A. Breathing Resistance Tests

1. Inhalation/exhalation peak ΔP (cm H_2O)

B. Canister Duration Tests

1. CO_2 level out of scrubber, expressed as a percentage of SEV

2. CO_2 level into scrubber, expressed as a percentage of SEV

COMPUTED PARAMETERS

Respiratory work in kg m/liter tidal volume was computed from ΔP vs. tidal volume plots obtained from breathing resistance tests.

DATA PLOTTED

A. Breathing Resistance Tests

1. Total breathing resistance vs. depth

2. Respiratory work vs. depth at constant RMV and supply pressure

B. Canister Duration Tests

1. CO_2 (% of SEV) out of scrubber vs. time

RESULTS AND DISCUSSION

BREATHING RESISTANCE TESTS

Breathing resistance was measured at five RMVs to simulate light through extreme diver work rates. Light work was measured at 22.5 RMV, moderate work at 40 RMV, moderately heavy work at 62.5 RMV, heavy work at 75 RMV, and extreme work at 90 RMV. These tests give a comprehensive look at the full range of MK 11 MOD 0 performance.

Breathing resistances plotted are the peak exhalation to peak inhalation values measured during one complete breath at a given depth and RMV. Peak to peak values, rather than individual inhalation and exhalation data, are plotted since it is impossible to reduce the data into exact individual components on closed and semi-closed circuit UBA.

In general, at 22.5 and 40 RMV each inhalation and exhalation value contributed approximately 50% to the total breathing resistance (Figure 3). At 62.5 through 90 RMV, exhalation resistance represented about 60% of the total value plotted. This is to be expected since the placement of the CO_2 absorbent canister in the exhalation flow path adds a small but measurable amount of resistance over that experienced upon inhalation.

Analysis of the data shows breathing resistance to be less than 25 cm H_2O in either direction at all RMVs tested at depths to 650 fsw. Breathing effort increased dramatically at 725 fsw at RMVs over 62.5. This is a strong indication that at heavy work rates the MK 11 breathing loop is reaching its design limit at depths over 650 fsw.

BREATHING WORK

Breathing work is defined as the external respiratory work required by the diver to operate his UBA. Since work is equal to pressure multiplied by the change in volume, respiratory work can be measured as a function of the area enclosed within the pressure-volume loop generated during breathing resistance tests (see Figure 4). While peak inhalation and exhalation pressures offer satisfactory data for evaluating UBA performance, breathing work is a more accurate indication of rig performance.

Figure 5 plots breathing work versus depth at all RMVs tested. Work levels were below 0.30 Kg m/l at all RMVs tested to 650 fsw. However, 725 fsw produced respiratory work requirements which were beyond 0.30 Kg m/l at 62.5 RMV and higher.

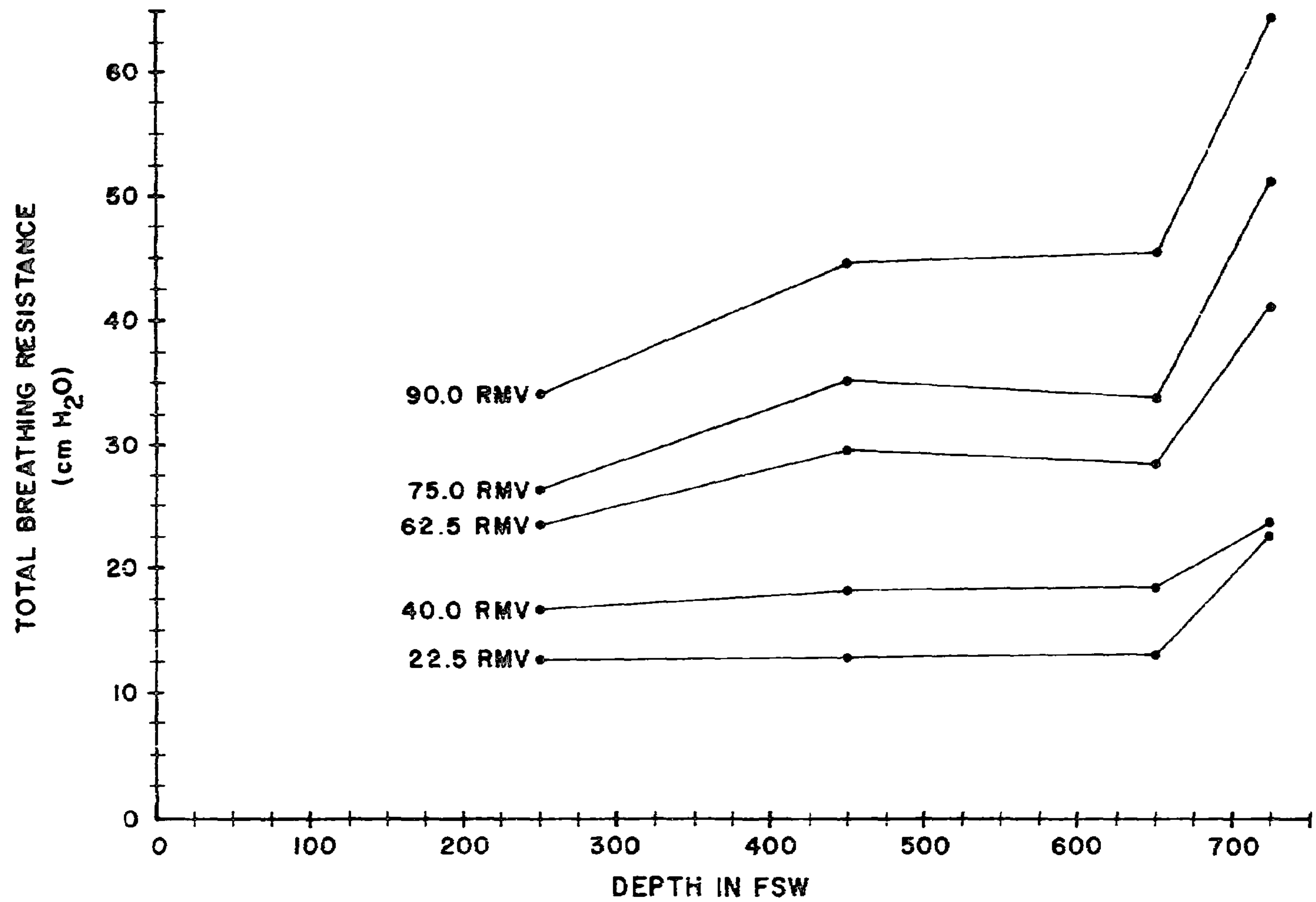
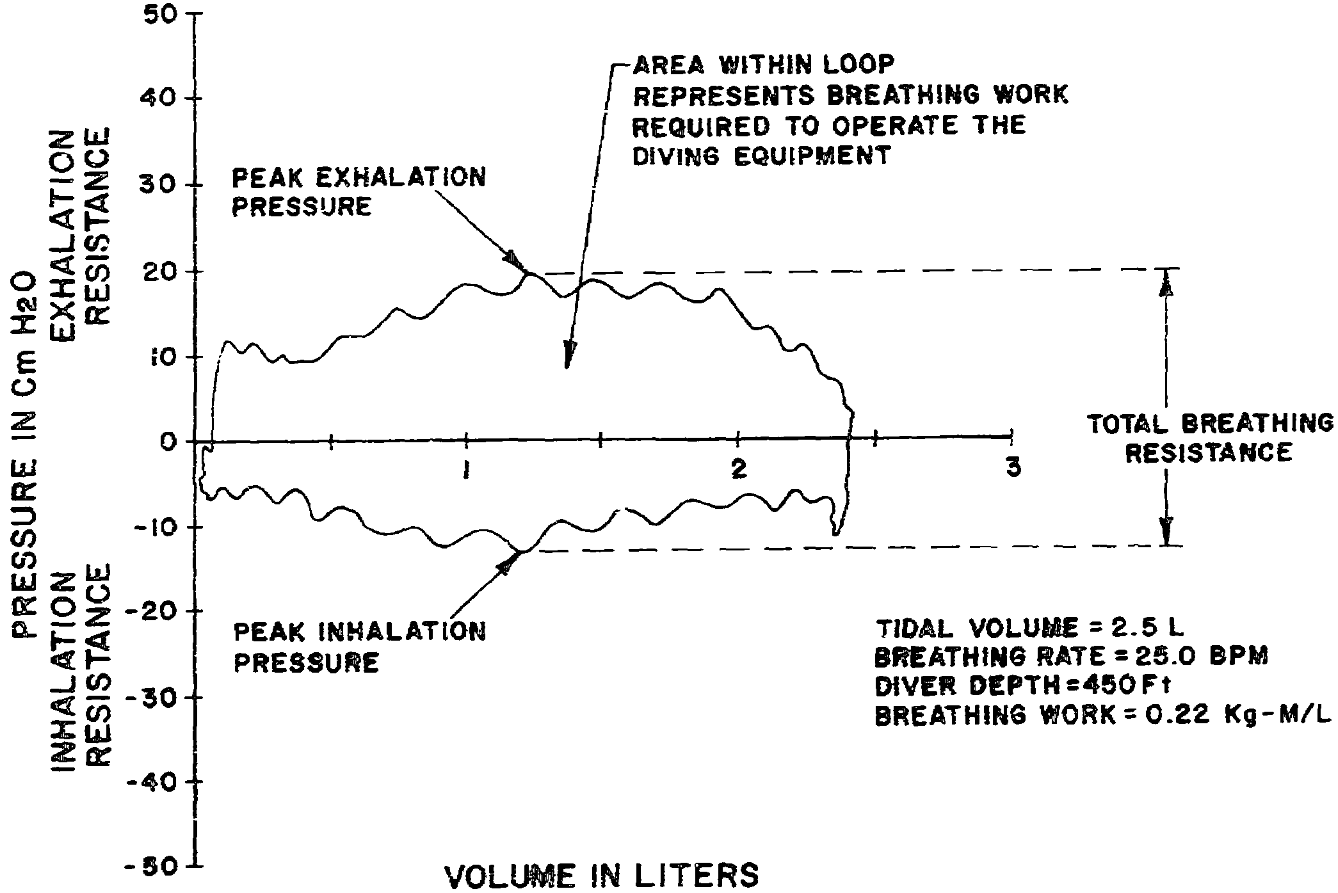


FIGURE [illegible]. BREATHING RESISTANCE VERSUS DEPTH



BREATHING PRESSURE VERSUS TIDAL VOLUME LOOP

FIGURE 4. SAMPLE PRESSURE-VOLUME LOOP

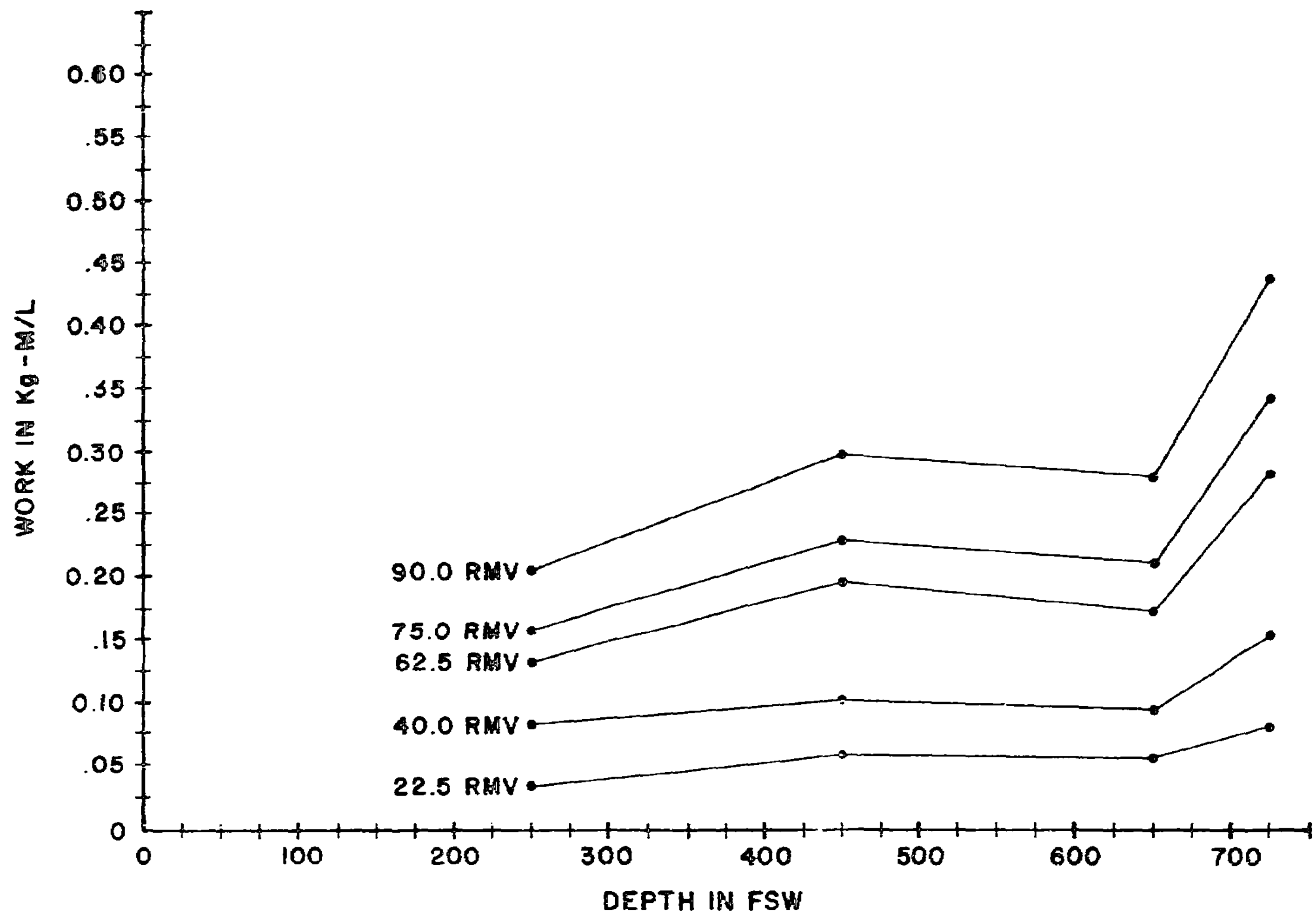


FIGURE 5. BREATHING WORK VERSUS DEPTH

CANISTER DURATION TESTS

The MK 11 MOD 0 absorbent canister incorporated Field Change Number 979A. This included a modified canister configuration containing a heated central core. The purpose of this heated core was to help maintain the absorbent temperature at a sufficiently high level to improve canister durations. Duration tests were conducted at depths ranging from 250 to 725 fsw. Ambient water was varied between 30, 35 and 40°F, while hot water to the canister outer jacket and heated core was varied between 95 and 110°F. A minimum of 4 tests were run for each set of test conditions which are summarized, along with the mean times to 0.5% CO_2 SEV and 1.0% CO_2 SEV, in Table 1. These results are also plotted in Figures 6 through 13. All tests were conducted using a rest/work cycle sequence of CO_2 addition to simulate the manned canister duration tests conducted by NEDU in the OSF (see Test Procedure). In addition, diver exhaled gas temperature and relative humidity were controlled to accurately simulate a working diver.

Canister durations given in Table 1 are the mean of four runs, and the data plotted in Figures 6 through 13 are those tests which most closely approached the mean values, respectively. It is important to note that canister test results under the same test conditions were quite erratic. Durations varied as much as 50 minutes between identical tests. Absorbent canisters normally vary no more than 20 minutes from run to run under identical unmanned test conditions. This wide variance in the data is a strong indication that the canister design is marginal at the depths and temperatures evaluated. While significant gains in duration were achieved at 250 and 450 fsw over previous designs (reference 1), most of these gains were lost at 650 and 725 fsw in ambient water temperatures below 40°F.

One problem was noted during canister duration tests. There is an erratic tendency for blow-by at the Koegel check valves in the M-11 mask. At non-periodic intervals the valves start to leak which causes high CO_2 concentrations in the diver's inhaled gas, even if the scrubber is still functioning properly.

TABLE 1

SUMMARY OF MK 11 MOD 0 (FC#979A)
UNMANNED CANISTER DURATION RESULTS

Figure No.	Depth (fsw)	Ambient H_2O Temp (°F)	Canister H_2O Temp (°F)	Mean Time (min) to 0.5% CO_2 SEV ±sd	Mean Time (min) 1.0% CO_2 SEV ±sd
6	250	35	110	268 ±10.6	298 ±11.7
7	450	35	110	245 ±15.4	270 ±14.1
8	650	30	95	142 ±09.34	164 ±12.9
9	650	30	110	151 ±17.7	181 ±17.8
10	650	35	95	156 ±16.6	177 ±16.1
11	650	35	110	199 ±22.8	234 ±19.03
12	650	40	110	227 ±19.2	260 ±15.1
13	725	35	110	166 ±05.5	199 ±13.9

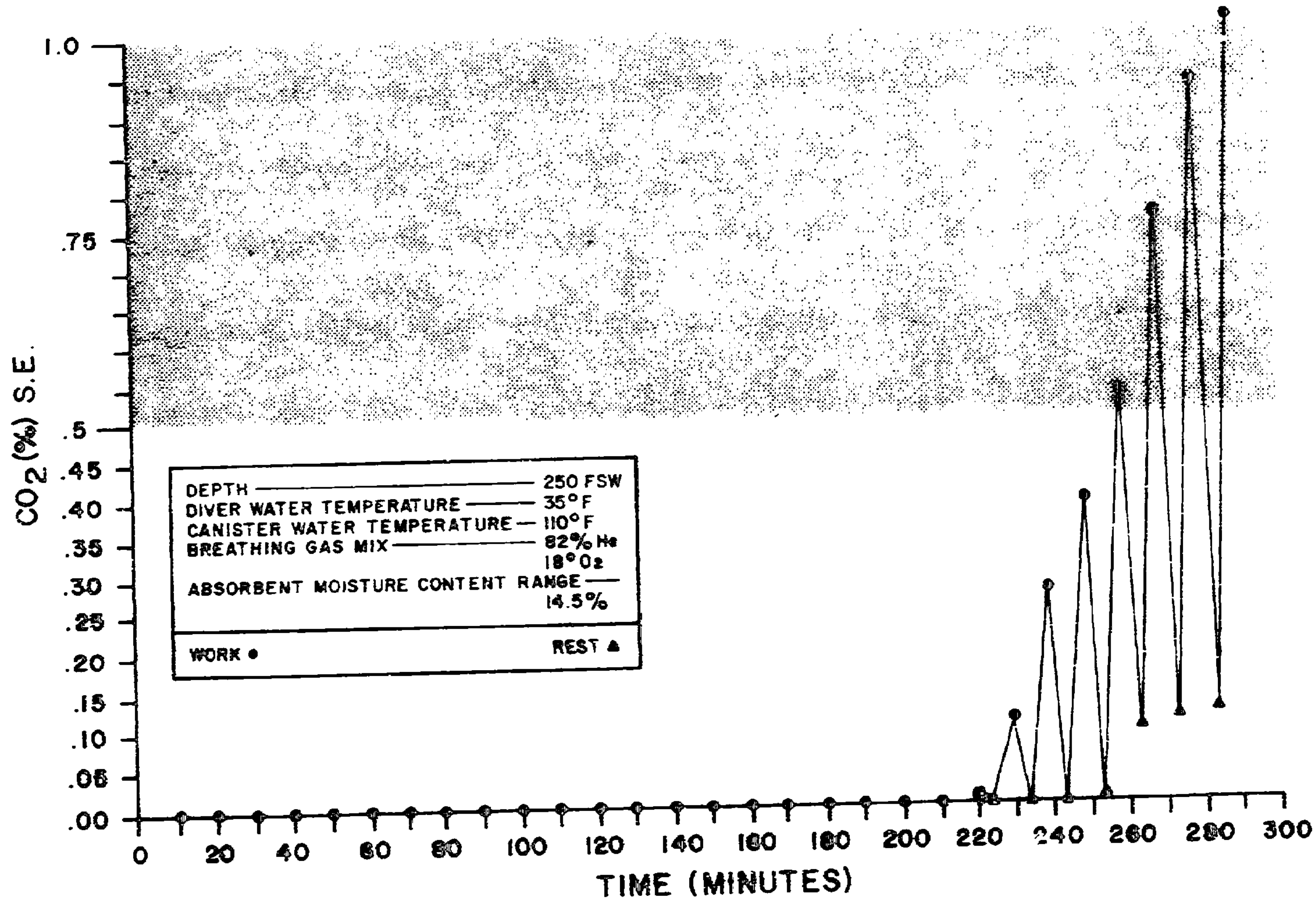


FIGURE 6. PERCENT CO_2 OUT OF SCRUBBER VERSUS TIME

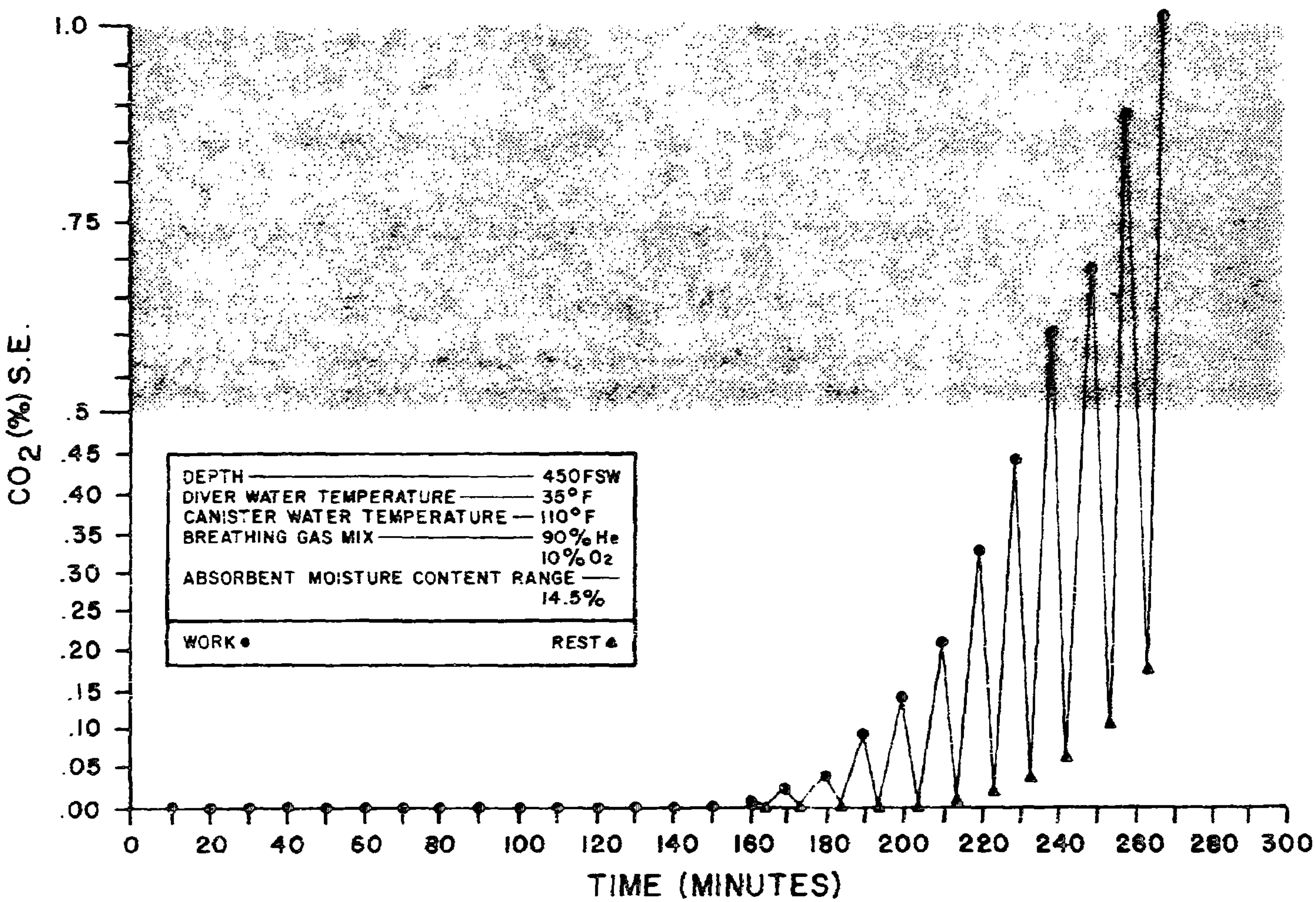


FIGURE 7. PERCENT CO_2 OUT OF SCRUBBER VERSUS TIME

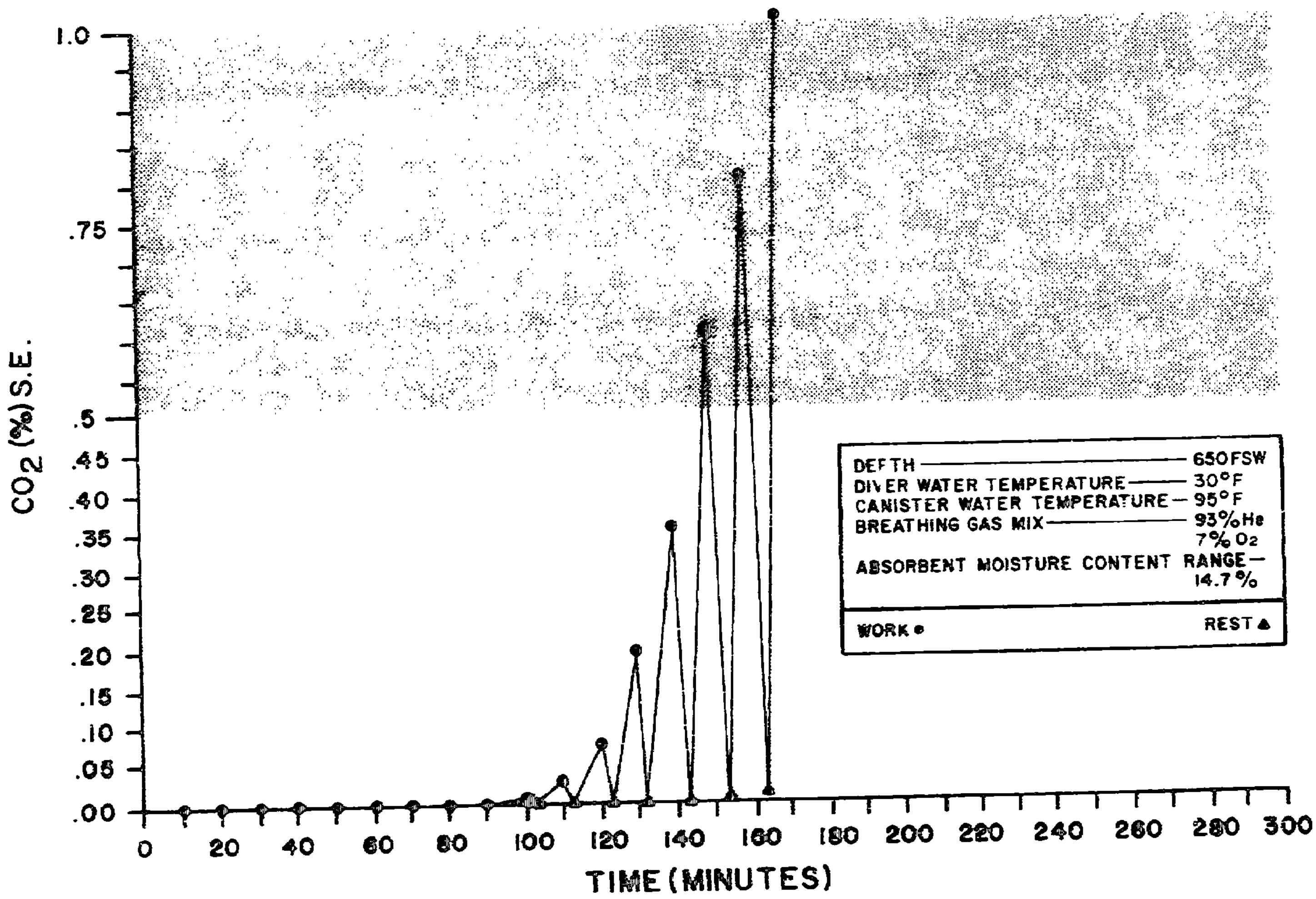


FIGURE 3. PERCENT CO_2 OUT OF SCRUBBER VERSUS TIME

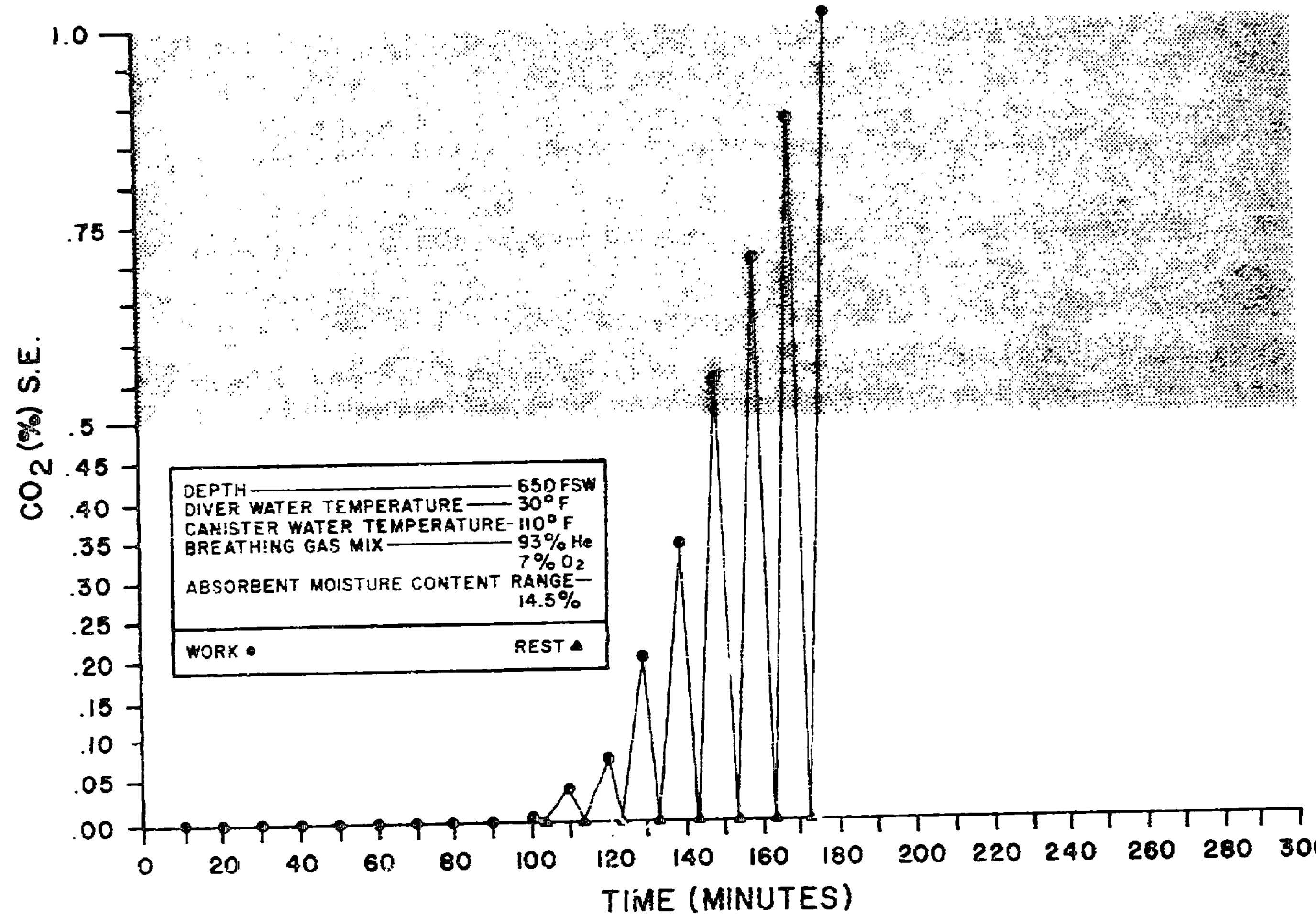


FIGURE 9. PERCENT [illegible] VERSUS TIME

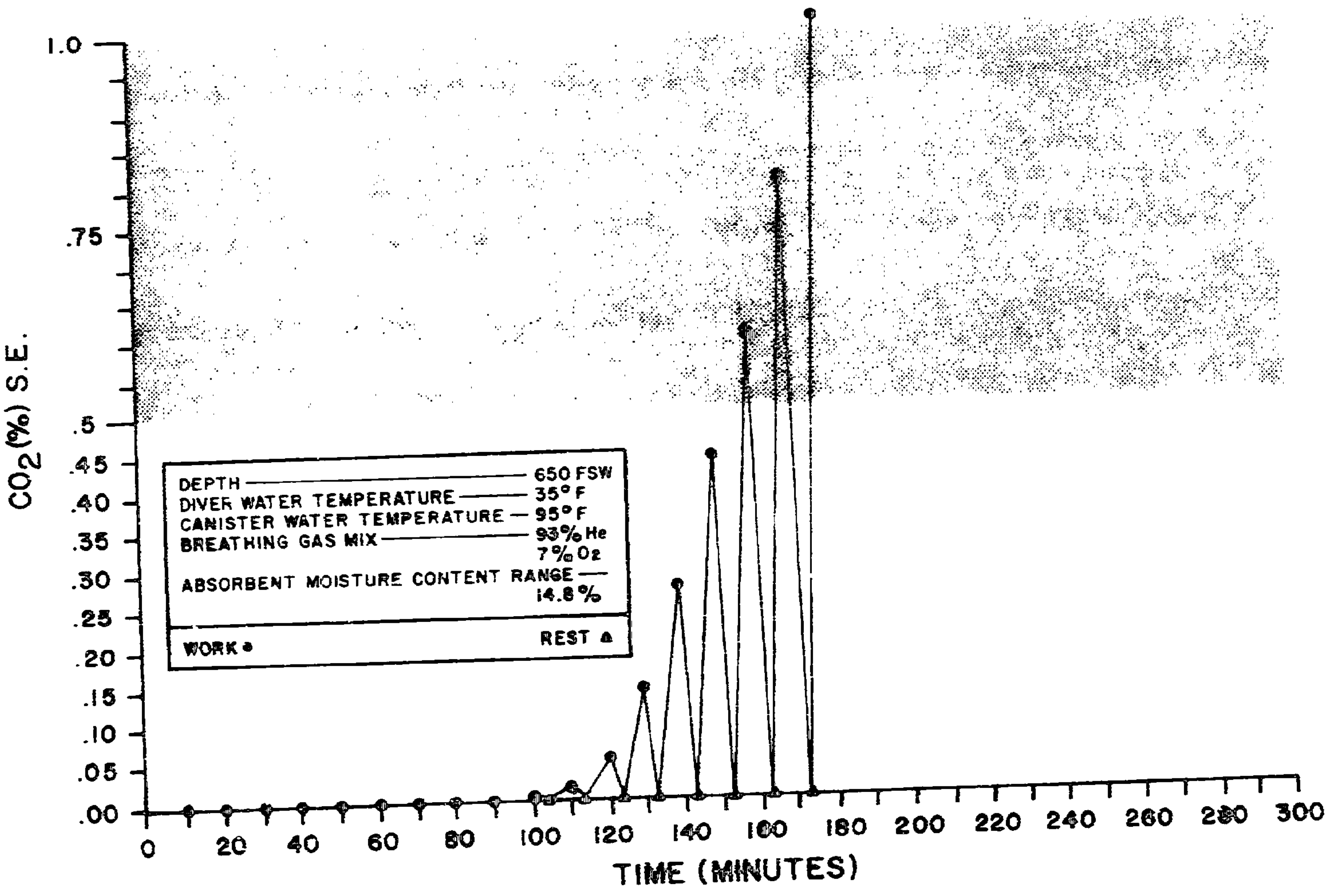


FIGURE 10. PERCENT CO_2 OUT OF SCRUBBER VERSUS TIME

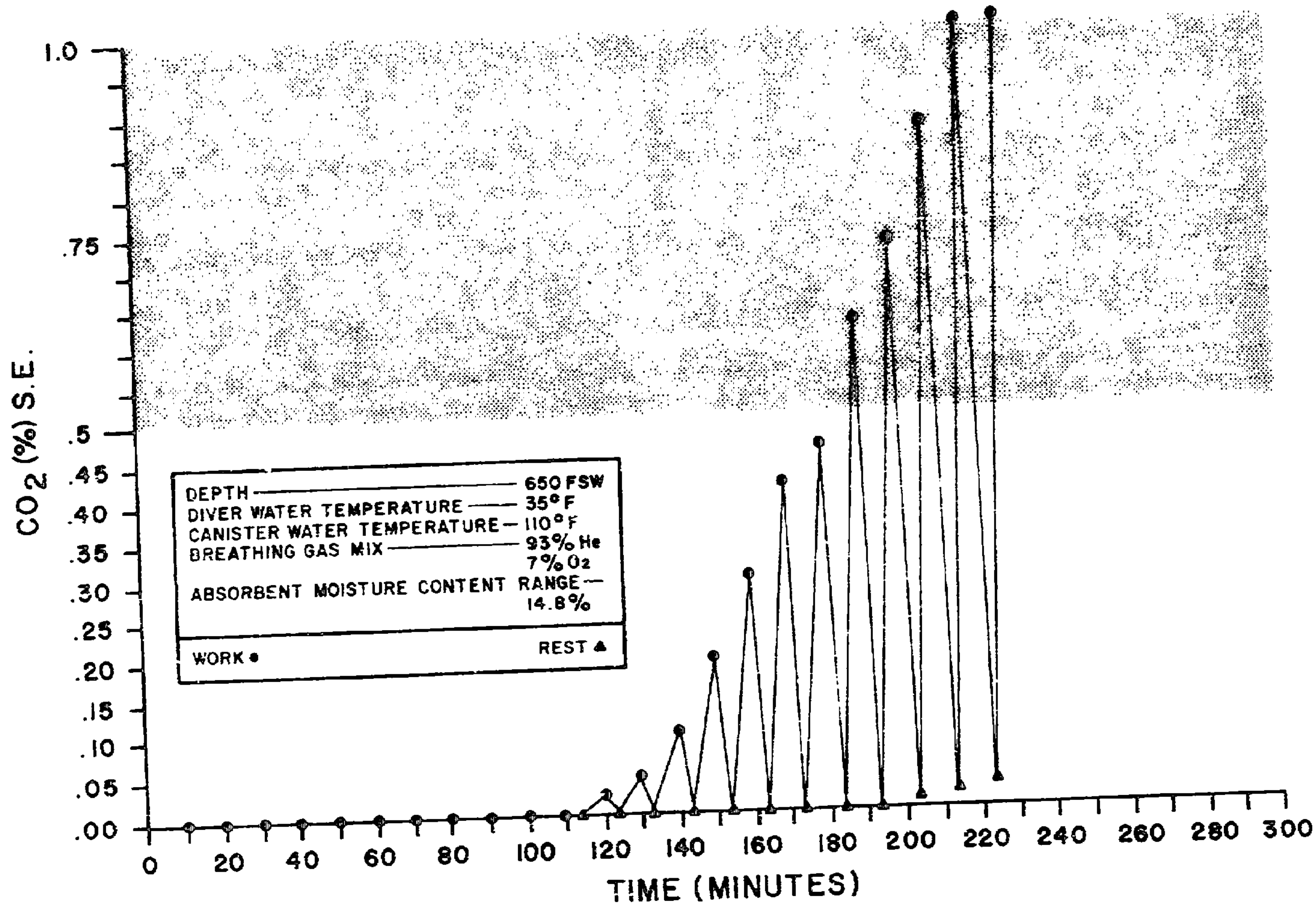


FIGURE 11. PERCENT CO_2 OUT OF SCRUBBER VERSUS TIME

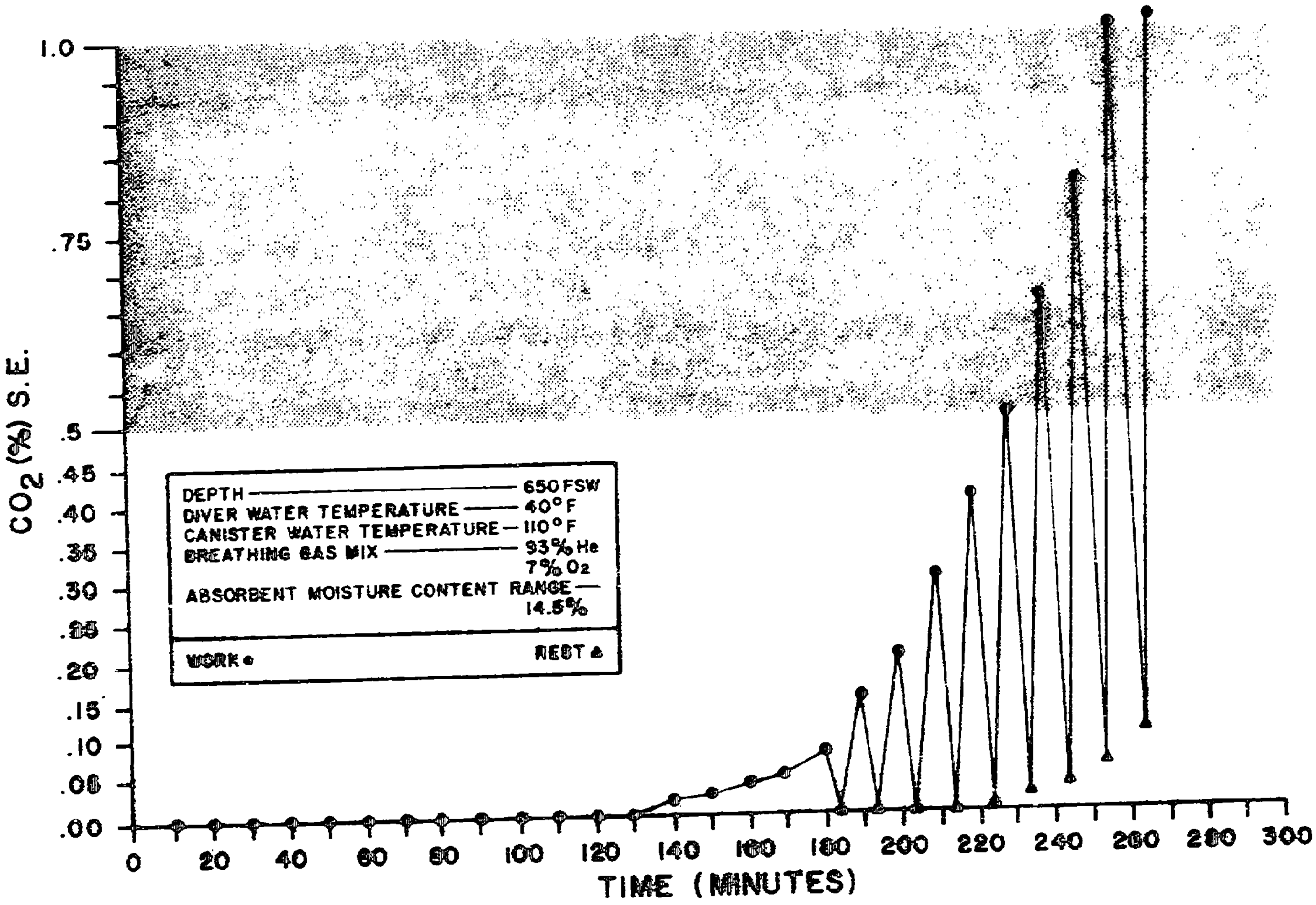


FIGURE 12. PERCENT CO_2 OUT OF SCRUBBER VERSUS TIME

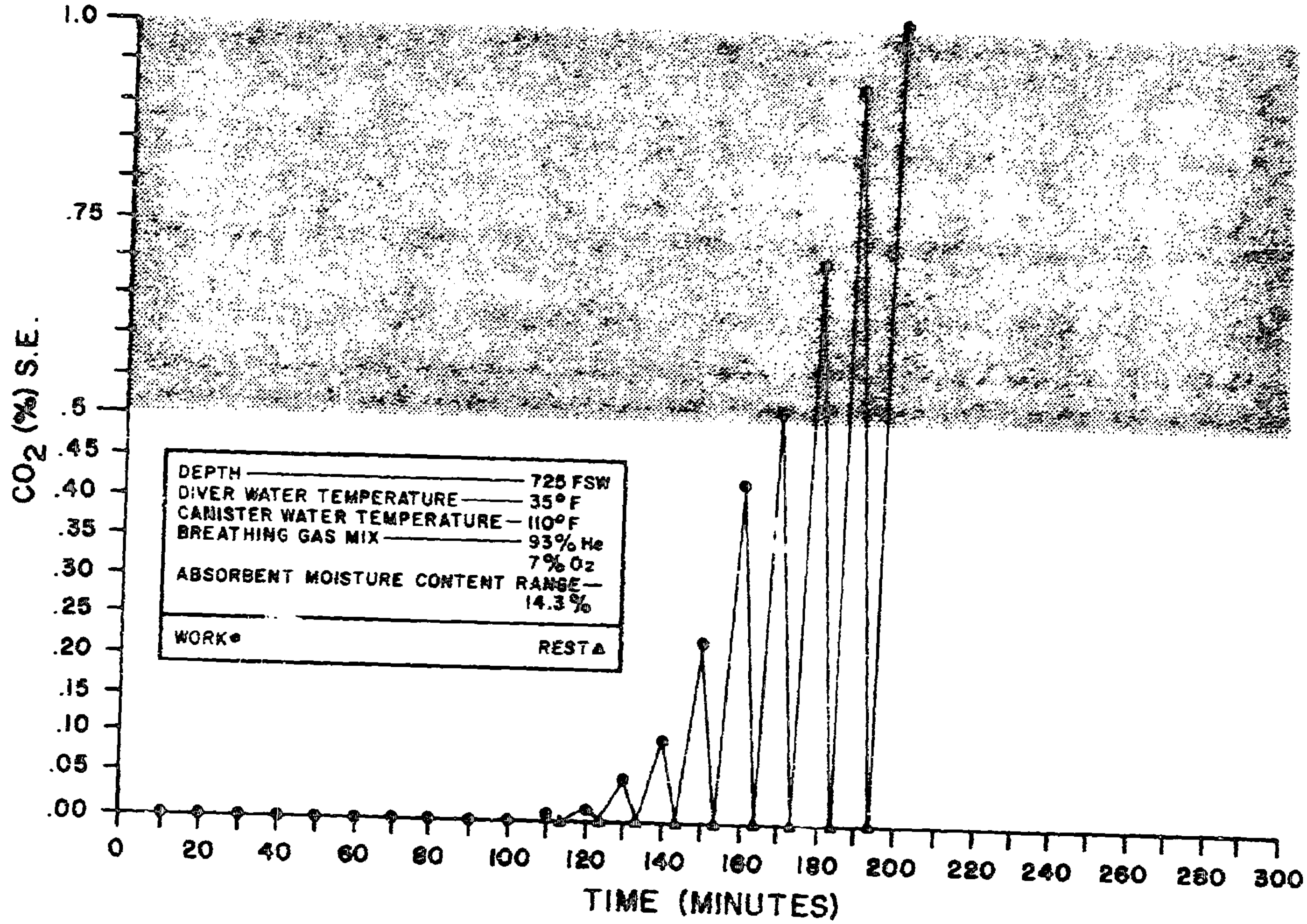


FIGURE 13. PERCENT CO_2 OUT OF SCRUBBER VERSUS TIME

CONCLUSIONS

Field Change #979A has produced considerable improvement in the breathing resistance and breathing work characteristics of the MK 11 MOD 0. However, the occasional tendency for the Koegel check valves in the M-11 mask to leak gas is a potential problem. Low resistance replacement valves such as the mushroom valves found in the AGA A.C.S.C. Full Face Mask have been shown to perform as well as the Koegels but provide a more positive check valve function.

Canister durations were improved at 250 and 450 fsw with FC#979A. However, most of the gain was lost at 650 fsw or deeper in water below 40°F. This fact, coupled with the erratic duration and times which were measured under identical test conditions, indicates that the design is marginal.

REFERENCES

1. NEDU Report 18-78, "Life Support Characteristics of the MK 11 Semi-Closed Mixed Gas UBA at Intermediate Depths."

2. NEDU ltr. 3939 Ser 492 dtd 21 December 1979.

APPENDIX A

TEST PLAN FOR BREATHING RESISTANCE TESTS

1. a. Ensure that MK 11 is set to specification and is working properly

   b. Chamber on surface

   c. Calibrate transducers

   d. Open make-up gas supply valve to test UBA

   e. Pressurize chamber to 250 fsw

   f. Adjust breathing machine to 1.5 liter tidal volume and 15 BPM and take readings

   g. Adjust breathing machine to 2.0 liter tidal volume and 20 BPM and take readings

   h. Adjust breathing machine to 2.5 liter tidal volume and 25 BPM and take readings

   i. Adjust breathing machine to 2.5 liter tidal volume and 30 BPM and take readings

   j. Adjust breathing machine to 3.0 liter tidal volume and 30 BPM and take readings

   k. Stop breathing machine

2. a. Pressurize chamber to 450 fsw

   b. Repeat Steps 1f thru 1k

3. a. Pressurize chamber to 650 fsw

   b. Repeat Steps 1f thru 1k

4. a. Pressurize chamber to 725 fsw

   b. Repeat Steps 1f thru 1k

5. a. Bring chamber to surface

   b. Check calibration on transducers

TEST PLAN FOR CO_2 CANISTER DURATION EVALUATION

1. a. Ensure that MK 11 is set to specification and is working properly using H.P. sodasorb

b. Chamber is on surface

c. Calibrate transducers and Beckman 865 Analyzer

d. Open makeup gas supply valve to test UBA

e. Pressurize chamber to 250 fsw

f. Water temperature to be 35°F

g. Canister inlet water temperature to be 110°F

h. Start humidity add system

i. Start CO_2 add and maintain following procedure until 1.0% SEV CO_2 is reached:

4 minutes at 0.9 LPM CO_2 add/2.0 liter tidal volume and 11.5 BPM

6 minutes at 2.0 LPM CO_2 add/2.0 liter tidal volume and 25 BPM

j. Take data every 10 minutes to breakthrough

2. Repeat Steps 1a - 1j with the following number of tests at each depth/water temperature combination:

Ambient Water Temperature (°F)		40	35	30
Canister Inlet Water Temperature (°F)		110/95	110/95	110/95
Depth (FSW)	250	-	4/-	-
	450	-	4/-	-
	650	4/-	4/4	4/4
	725	-	4/-	-

APPENDIX B

TEST EQUIPMENT

1. Breathing machine CO_2 add system/humidity add system

2. Validyne DP-15 pressure transducer w/1.00 psid diaphragm (oral pressure)

3. Wet test box

4. The heating and cooling systems from the EDF life support loop to control water temperatures

5. MFE Model 715M X-Y plotter

6. Validyne CD-23 transducer readout (1 ea)

7. Beckman 865 Infrared Analyzer for analyzing CO_2 out of scrubber

8. Beckman 865 Infrared Analyzer for analyzing CO_2 into scrubber

9. NEDU EDF chamber complex

10. Chamber depth gauge

11. External gas supply pressure gauge

12. Test UBA: MK 11 MOD 0

13. Hydrodynamics relative humidity sensor

14. Breathing machine piston position transducer

15. Gould Brush Model 2600 strip chart recorder

16. YSI Model 701 thermistors for monitoring wet box and canister inlet water temperatures (2 ea)

17. Digitec Model 5820 thermistor readouts (2 ea)